ELECTRONIC FUNDAMENTALS

THEORY LESSON 28

TRF RECEIVERS

28-1. The TRF Amplifier Stage
28-2. Tuned Grid Impedance
28-3. Selectivity and Noise Suppression
28-4. Tuning by Varying the Inductance
28-5. The Need for Constant Bandwidth
28-6. Variable Capacitors
28-7. Variable Capacitor Plate Shapes
28-8. Triode TRF Amplifiers
28-9. Ganged Variable Capacitors

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Theory Lesson 28

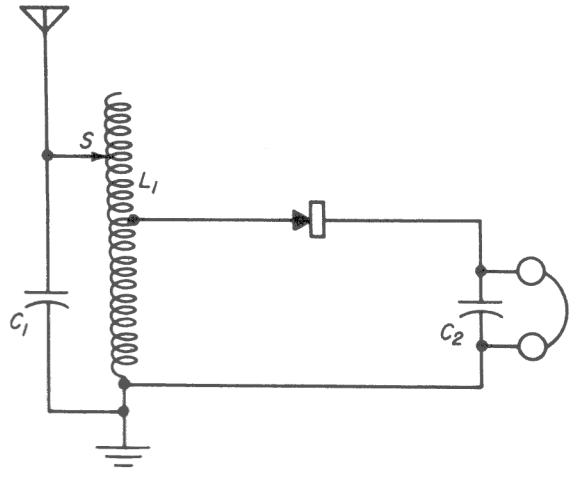
INTRODUCTION

The first radio receivers used by the public were simple sets that used crystal detectors to rectify the signal and thereby separate the audio information from the carrier. Figure 28–1 shows an early circuit of such a receiver. The receiver could not amplify. Only the rectified signal supplied the power needed to move the diaphragms of the earphones, and only a strong signal had enough power to move the diaphragms. So the set could receive strong signals only.

In order to pick up the maximum possible signal, long, roof-top antennas were used. The set was tuned by means of the coil and capacitor combination, $L_1 C_1$, called a sliding tuner, which was adjusted to resonance at the frequency of the desired signal by moving the sliding contact, S, along L_1. But the Q of the tuner was very low because the tuner was loaded by the crystal detector and the non-resonant antenna. So, if a listener wanted to tune in one of two stations of equal signal strength on the air at the same time, he could do so only if the stations had carrier frequencies differing by two or three hundred kilocycles. The receiver could separate these stations well enough so that one station could be heard clearly with the other station slightly audible in the background. During the period when crystal sets were the only type in use, there wasn't room enough in the broadcast band for stations to have carriers so widely separated from each other. Stations only a hundred kilocycles or so apart interfered with each other.

There were other limitations, too. The signals from some stations were so weak that they could barely be heard even when no interfering carrier was on the air.

Also, the crystal detector suffered from interference caused by discharges of static



simple circuit of early crystal set

Fig. 28-1

electricity in the air, from sparking doorbells, electric motors, arc lights, and other sources of electrical impulses. These pulses were heard in the earphones as crackling, hissing, or frying sounds, and were generally called *static* by the public. Engineers call these sounds *noise*.

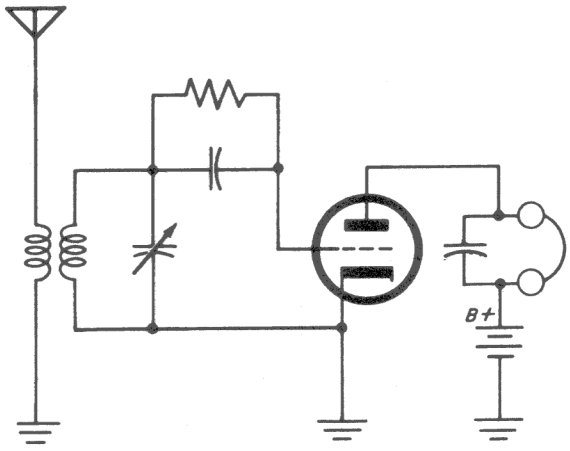
Later radio receivers were more effective than crystal sets because they were greatly improved in the following respects:

1. Sensitivity – the ability to respond to signals and produce an audible output. Very sensitive receivers produce audible output from very weak signals.

2. Selectivity – the ability to respond to the signals of a particular station and to discriminate against all other signals.

3. Noise suppression – the ability to reduce or eliminate electrical noise.

4. Fidelity – the ability to reproduce the audio information without sacrificing part of it, or distorting it. The goal was to make the reproduction so realistic that it could not



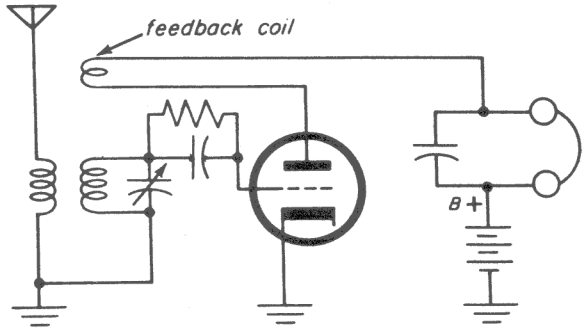
grid-leak detector

Fig. 28-2

be distinguished from the original sound. Public demand for this refinement did not develop until the first three improvements had been wholly, or largely, made.

In the later days of the crystal set, triode electron tubes appeared on the market. These tubes made it possible to make a set that was more sensitive than the crystal set. This was done by adding a stage of amplification to the crystal detector. Later, the crystal detector itself was replaced by the grid-leak detector, which used a tube that performed both detection and amplification. (See Fig. 28–2.)

When the grid leak detector was further improved by the invention of the regenerative detector (see Fig. 28–3), there was a tremendous improvement in radio reception. Regeneration increased sensitivity to weak signals as much as one hundred times. By means of feeding back r-f energy from the plate circuit to the grid circuit, the resistance of the input inductance was almost overcome. This greatly improved the effective Q of the tuned input circuit. With improved Q, the resonance curve of the circuit became much narrower. As a result, the set discriminated against signals whose frequencies differed



regenerative grid-leak detector

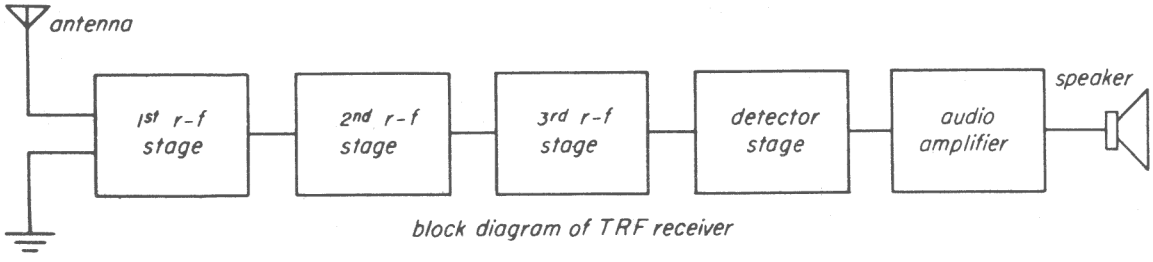
Fig. 28-3

considerably from the resonant frequency. But even though a set using regeneration improved both sensitivity and selectivity, conditions changed so that its performance was not satisfactory. Many new radio stations began to broadcast, and these stations were either so close together that there was interference even on the regenerative set, or, in some cases, their signals were so faint that they were not reproduced with audible volume.

The difficulties found in the sets using only a regenerative detector and an audio amplifier were solved by the *tuned-radio-frequency* receiver. This type of receiver, abbreviated TRF, provides amplification preceding detection, namely amplification of carriers. Furthermore, it amplifies only the frequencies desired. It is not limited to one stage of amplification, as was regeneration.

The output of one stage is amplified more by a similar following amplifier stage, and still another amplifier stage after that. The total amount of amplification before detection can be a thousand times or more. Such amplification makes extremely weak signals quite usable.

The characteristics of a parallel-resonant circuit, plus the ability of the electron tube



block diagram of TRF receiver

Fig. 28-4

to amplify a signal applied to its control grid, make such stages of amplification possible. Figure 28-4 is a block diagram of a TRF receiver.

Many refinements of the basic trf receivers followed the appearance of the earliest models, including a deluxe high-fidelity version with specially designed r-f transformer that gave the receiver's over-all resonance curve a broad bandwidth for desired signals but very sharp rejection of all signals outside the bandwidth of the station tuned in.

28-1. THE TRF AMPLIFIER STAGE

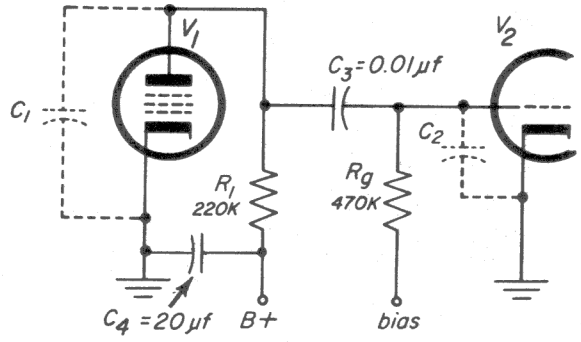
Let's consider how radio frequencies are amplified in a TRF set. In order to understand the process thoroughly, it is useful to review the way in which the plate load of an electron tube affects voltage amplification.

An electron tube provides voltage amplification because its plate current is made to vary by means of small changes of control-grid voltage. This causes a relatively large varying voltage drop across the plate-load resistor or the plate-load impedance.

The varying voltage drop across the load is much greater than the varying voltage on the grid. The varying voltage on the grid is a signal. The varying voltage drop across the plate load has the same pattern as the signal, but is greater in amplitude. The higher the resistance or impedance of the load, the larger is the voltage drop that a given plate current variation can produce in it – with certain important qualifications.

When the frequency goes up to the r-f range, the impedance of the interelectrode capacitances and stray external capacitances is so low that the capacitances have very little impedance for r.f. Thus the electrodes of the tube are considered to be at ground potential for r.f.

Let's consider what happens when r-f is applied to an amplifier such as the one shown



shunt capacitances in an R-C coupled stage

Fig. 28-5

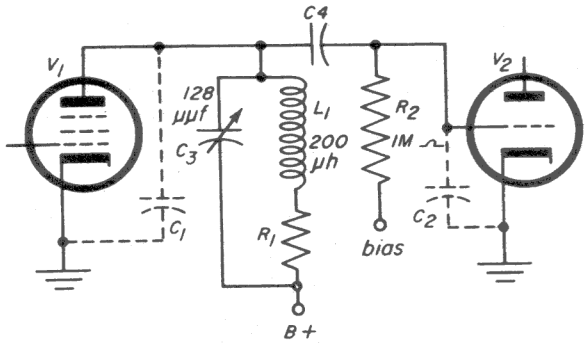
in Fig. 28–5. In the figure, the sum of interelectrode capacitances and stray external capacitances at the socket of V_1 are represented by C_1.

The total interelectrode capacitances of V_2 are represented by C_2. These interelectrode capacitances are in parallel with the load resistor R_1. Since C_1 and C_2 have an impedance that is much lower than the resistance of R_1, the r.f. is bypassed to ground through the low impedance.

The frequencies of carrier signals in the broadcast band are much higher than audio frequencies. A resistor with a value of 220 k-ohms, a value quite commonly used as the plate load of an audio amplifier, would be just about useless as the plate load of an r-f amplifier. Figure 28–5 shows why.

The bypassing effect could be reduced considerably by lowering R_1 to a few thousand ohms, thereby making the resistance of the load resistor equal to or less than the reactive impedance of the total stray capacitance. Then the capacitance would not have so much bypassing effect.

But the gain due to the useful output voltage produced by the tube's plate current changes would be largely reduced, because a given plate-current change produces less voltage change across a plate load resistor with less resistance. With the best available tube and the best value of resistor, there could be a gain of about 10 times around the middle of the broadcast band.



tuned-plate-impedance r-f amplifier stage

Fig. 28-6

But if the plate-load resistor is replaced by a tuned-plate impedance – that is, by a parallel-resonant circuit – the behavior of the amplifier is completely different. Consider the circuit shown in Fig. 28–6.

Tuned-Plate-Impedance R-F Amplifier. The tuned circuit in Fig. 28–6 consisting of L_1 and C_3 is tuned to the carrier frequency by means of adjusting the variable capacitor, C_3. (Any signal which develops across L_1 is coupled to the grid of V_2 through capacitor C_4.) R_1, a few ohms, is the resistance of the wire in L_1. As far as the d.c. for the plate of V_1 is concerned, L_1 has a very low resistance and the d-c voltage drop is negligible. But for a signal at the resonant frequency, the reactive combination L_1 and C_3, offers a high impedance, and is equivalent to a resistor of about 60,000 ohms. If V_1 has a *mu* of 2,000 micromhos, the gain at resonance will be over 100.

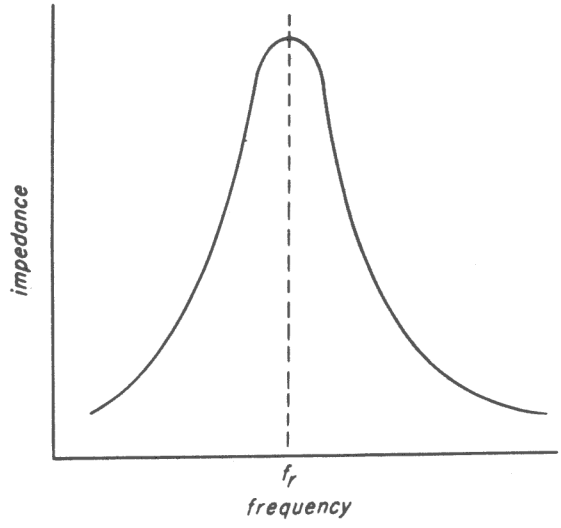


Fig. 28-7

The bypassing or shorting effect of the stray capacitances, C_1 and C_2 that caused a loss of signal from plate to ground and from grid to ground in the simple resistance-coupled amplifier is not felt in the tuned r-f amplifier, because of the parallel-resonant circuit. The stray capacitances simply act like part of the desired tuning capacitance, C_3, and resonate with the inductance. The presence of the inductance completely changes their adverse effect.

Shown in Fig. 28–7 is an impedance curve plotted against frequency for a parallel-resonant circuit. We know that when an inductor and a capacitor are connected in parallel, they form a parallel-resonant circuit at the resonant frequency(F_r).The impedance at resonance is very high – higher than the impedance of either component alone. We know that the gain of a pentode stage is:

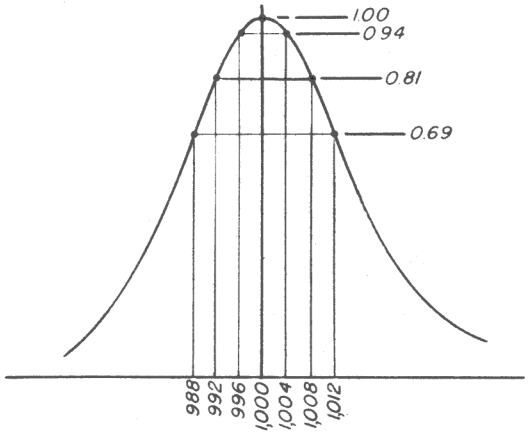
$$A = G_m Z_L$$

Since the impedance will be highest at the resonant frequency, the gain and the output voltage will be highest. At frequencies above and below resonance, the impedance will decrease and so will the gain and output voltage decrease.

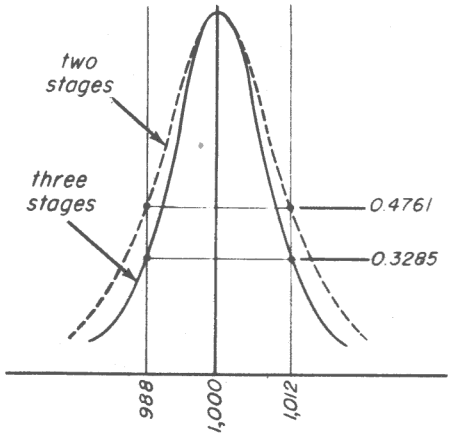
In this way, resonant circuits favor signals whose frequencies are at or very close to resonance, and discriminate against signals whose frequencies differ considerably from resonance. Stated in terms of gain, a tuned circuit provides gain for signals whose frequencies are at or close to resonance, and less gain for frequencies not so close to resonance.

For a circuit such as that in Fig. 28–6, design engineers using appropriate formulas can calculate the relative gain of the stage for a range of frequencies.

Knowing the relative gain over a range of frequencies will indicate the selectivity of a circuit. Therefore, it lets us know quantitatively how the stage favors one frequency and rejects others. For the component values already assigned to Fig. 28–6, a table of relative gain for various frequencies follows. The table is based upon full gain, at resonance, being unity (1). Then, as you can see, the relative gain at



(a)



(b)

Fig. 28-8

any frequency other than the resonant frequency is less than 1.

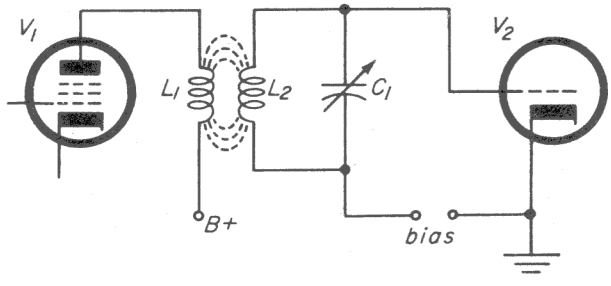
Frequency (kc)	Relative Gain
988	0.69
992	0.81
996	0.94
1000 (resonance)	1.00
1004	0.94
1008	0.81
1012	0.69

From the table of relative gain, we can draw the resonance curve of the circuit, as shown at *a* in Fig. 28–8. It is rather broadly resonant. One stage of such amplification would not be very selective. Although the circuit resonates at 1,000 kc, signals as far away from the resonant frequency as 988 kc 1012 kc would experience 69 percent as much as gain as those at resonance. This is too much in proportion to the gain at resonance. However, if two stages are used, signals at 988 kc and at 1,012 kc would experience gain equal to 69 percent of 69 percent of gain at resonance, or 0.69 x 0.69 x 1, or 47.61 percent. Signals at resonance would still experience full gain.

If three such stages are used, signals at 988 kc and at 1,012 kc will experience only 0.69 x 0.69 x 0.69 x 1, or 32.85 percent of the gain experienced by signals at resonance. Thus, the more stages we use, the narrower the over-all resonance curve becomes, as shown in Fig. 28-8*b*. That is, the more tuned stages we use, the more selective the receiver becomes.

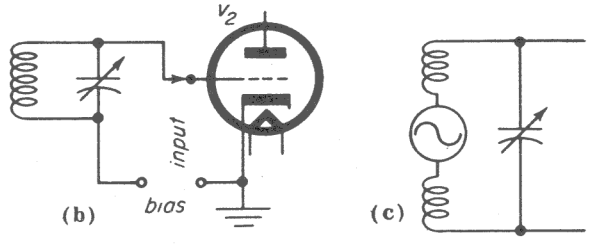
28-2. TUNED GRID IMPEDANCE

Figure 28-9*a* shows another circuit for a trf stage. In this circuit, the plate circuit is untuned, but the following grid circuit is tuned. Coupling between plate and grid circuits is by mutual inductance, that is, by lines of magnetic force shared by L_1 and L_2. As the plate current through L_1 varies, and the field around it expands and collapses, the lines of force are cut by the turns of L_2, and a current is induced in L_2. A voltage is developed across its terminals, and across variable capacitor C_1. This voltage is applied to the grid of V_2.



tuned-grid transformer-coupled r-f stage

(a)



The tuned secondary acts as both a parallel and a series resonant circuit

Fig. 28-9

Note that the primary of the transformer, L_1, is not resonated by a capacitor across it. This time we are not trying to develop a high signal voltage *across* it, and transfer that voltage through a capacitor to the following grid, as we did with the circuit of Fig. 28-6. This time we are more interested in a *high signal current* through it, because we want as many lines of force as we can get to expand and collapse as the signal alternates. The more lines of force we get, the more energy we induce in the resonant circuit that is magnetically coupled to L_1. That is, the more energy we induce, the more *power* we get into the resonant circuit, and the higher will be the voltage developed across L_2 and C_1.

The resonant circuit behaves in different ways to the two other circuits coupled to it. To the input circuit following it, it is a parallel-resonant circuit, as shown at *b* in Fig. 28-9.

To the plate circuit preceding it, it is a series-resonant circuit. At *c* in the figure the equivalent circuit is shown. It is as though the coil were opened at the center and a generator were inserted in series with it. The generator represents the magnetic energy coupled into the coil by the magnetic lines of force and inducing a voltage in L_2. Thus, the induced voltage is connected in series with L_2 and C_1, and the circuit can be considered as a series resonant circuit. Because of the series-resonant circuit, there is a Q resonant rise of voltage across L_2 and C_1.

The resonant circuit, coupled in series, presents a low impedance to the plate circuit's magnetic energy, and, therefore, absorbs power. To the grid-cathode circuit of the following tube, connected in parallel with it, it presents a high impedance, across which the absorbed power develops a voltage at the signal frequency.

By varying the physical distance between the primary and the secondary, or by using either more or fewer turns on the primary, or by doing both, the degree of coupling between primary and secondary can be adjusted by the transformer designer. His decision as to how much coupling to use will be affected by the degree of selectivity desired, the number of stages to be used, the desired gain per stage and other factors.

28-3. SELECTIVITY AND NOISE SUPPRESSION

Elimination of Noise. Adequate selectivity in a receiver excludes more than just undesired interfering carriers. It also substantially reduces electrical noise.

Consider a sparking interrupter-type doorbell. Not only are the voltages of the spark impulses surprisingly high, but the band of frequencies transmitted by the spark is very wide. The spark emits energy throughout the usable radio spectrum, and beyond – from audio frequencies to ultra-high frequencies.

The broadly tuned, or untuned, crystal detector, was subject to interference from this type of noise. But the well-designed TRF receiver responded to only a narrower portion of the spark's wide band. Because of its selectivity, it could tune out a large part of the energy that the crystal set accepted and detected. The more selective the TRF receiver was, the more immune it became to noise interference. Yet designers did not attempt to make it super-selective.

There is a serious drawback to extreme selectivity in receivers intended for the enjoyment of broadcast reception. Extreme selectivity impairs the quality of the reproduced audio information, because over-selective circuits reject certain off-resonant frequencies, called sidebands, transmitted by the station.

Sidebands and Bandwidth. Up to now, we have been speaking of a modulated envelope. This envelope has three separate parts. For example, let us consider a carrier frequency of 1,000 kc, and a 10-kc modulating signal superimposed upon it. We have spoken of this as a 1,000-kc carrier modulated with a 10-kc envelope, and we have shown it in the

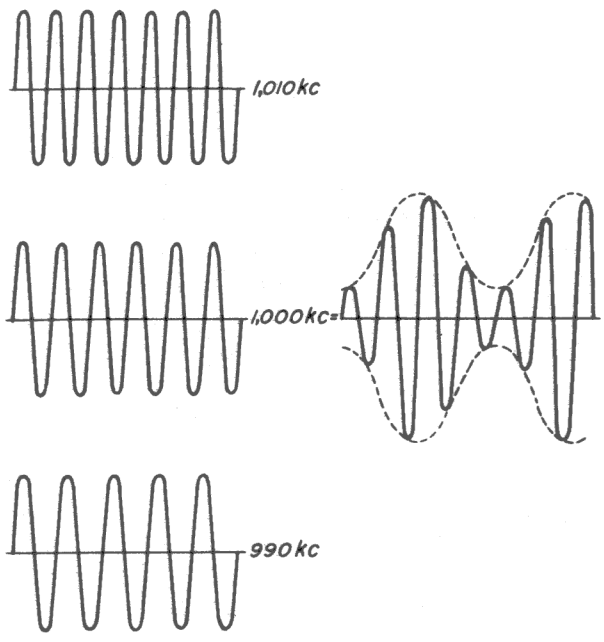


Fig. 28-10

way it is shown at the right of Fig. 28-10. However, this modulated carrier is made up of the separate portions shown – a 1,000-kc carrier, and *sidebands*. One sideband is equal to the carrier frequency plus the modulation frequency, and the other sideband equals the carrier frequency minus the modulation frequency. The sidebands contain the audio information.

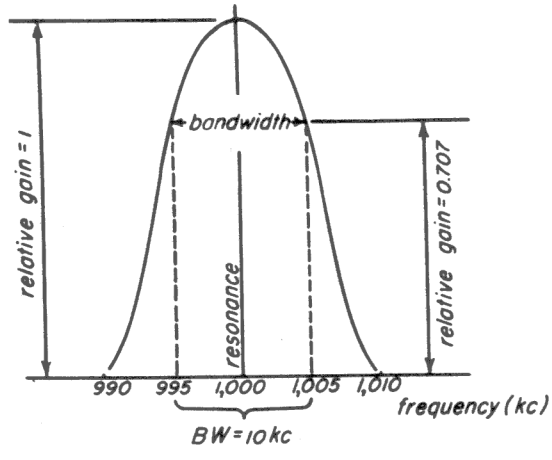
When the carrier and sidebands reach the input to the detector of a radio receiver, the sidebands either reinforce or oppose the carrier signal (depending upon frequency relations), causing the carrier's effective amplitude to vary exactly as the audio signal varied when modulating the carrier at the transmitter.

The detector effectively combines the carrier and the sidebands, and detection takes place as described in an earlier lesson.

When a receiver is tuned to a station, it must tune in not only the carrier, but the sidebands as well. The sidebands should not be tuned out or considerably attenuated; otherwise the audio information that is reproduced may have the higher audio frequencies missing, or the higher frequencies may be reduced in amplitude relative to the lower audio frequencies. When one group of frequencies is missing or reduced in amplitude, the effect is called frequency distortion. It is desirable to avoid, or at least minimize, this effect.

Since a receiver that is too selective tunes out some of the sidebands, designers try to design sets with a selectivity that will just accept, or pass, these sidebands frequencies, but reject all frequencies beyond them. The range between the lowest sideband frequency of a carrier and the highest sideband frequency of the same carrier that a receiver will satisfactorily pass is called the *bandwidth*, or passband, of the receiver for that carrier frequency. An ideal receiver would have the same bandwidth for all carrier frequencies. Very few TRF receivers come close to meeting this requirement.

So far, we have spoken of passing sidebands without considering exactly what we mean by pass. In fact, standards have been set up for what is considered a satisfactory passing of frequencies. All frequencies for which a receiver yields a relative gain of 0.707 or more are considered as passed satisfactorily. Thus, if the curve in Fig. 28-11 represents the over-all resonance curve of a certain TRF receiver, the tuned circuits are said to pass satisfactorily all frequencies between 995 kc and 1,005 kc. The bandwidth or passband of the receiver, the difference between 995 kc and 1,005 kc, is 10 kc.



bandwidth of a certain receiver at 1,000 kc

Fig. 28-11

28-4. TUNING BY VARYING THE INDUCTANCE

In the two types of r-f amplifier so far considered, the resonant frequency of the stage was changed by varying the capacitance, while the inductance remained fixed. It is also possible to change the resonant frequency by varying the inductance while the capacitance remains fixed.

Inductance may be varied in several ways. The most common and convenient method of varying inductance is the one that uses a powdered-iron slug that slides in and out of the coil form as the tuning knob is rotated (see Fig. 28-12).

The ratio of highest frequency in the broadcast band to the lowest frequency in the broadcast band is approximately three to one. The ratio of highest inductance to lowest inductance required to tune over the broadcast band is the square of the frequency ratio, or nine to one.

The reason why one ratio is the square of the other is found in the formula showing the relationship between L and the resonant frequency f.

$$f\,(\text{in kc}) = \frac{159{,}200}{\sqrt{L\ (\text{in } \mu\text{h}) \times C\ (\text{in } \mu\mu\text{f})}}$$

Simplifying to find L,

$$\sqrt{L \times C} = \frac{159{,}200}{f}$$

$$L \times C = \left(\frac{159{,}200}{f}\right)^2$$

$$L = \frac{\left(\frac{159{,}200}{f}\right)^2}{C}$$

Note that the quantity in parenthesis is squared. Therefore it must vary inversely as the square of any change in f.

In an actual problem, we would have to work out the value of L for two values of f, one value being three times the other, or $3f$. If you increase the value of f, you make the numerator of the fraction smaller. As a result, L becomes smaller. The ratio between L and f is inverse, when C is constant. When f increases, L decreases.

Modern powdered-iron coil cores have such high permeability – ability to concentrate magnetic lines of force – that they can increase the inductance of a plain solenoid coil more than nine times when fully inserted into it.

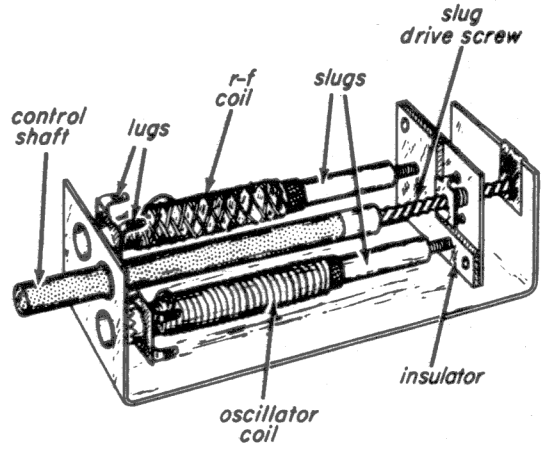


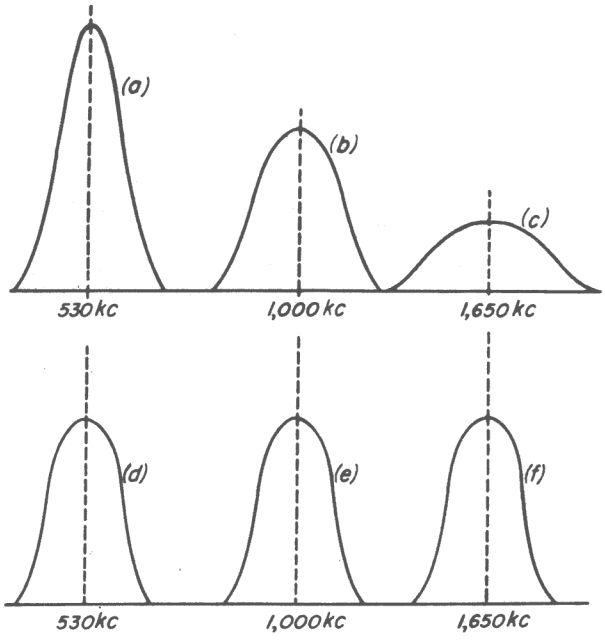
Fig. 28-12

The coil is wound so that its normal no-core inductance is the lowest required for the tuning range. As the core is gradually inserted by the tuning mechanism, the inductance gradually increases, until, when the core is fully in, the inductance reaches the required maximum.

At minimum inductance, the circuit is tuned to the high end of the broadcast band; at maximum, the low end.

28-5. THE NEED FOR CONSTANT BANDWIDTH

A professionally designed inductance-tuned, or capacitance-tuned r-f amplifier stage looks like a simple, easy-to-create arrangement. Its simplicity is mechanical only. Electrically there is much more to it than meets the eye. It represents a careful and intelligent choice of component values, carefully calculated coupling, appropriate L/C ratio, and many other considerations. For it attempts not only to cover the broadcast frequency range of three to one, but at the same time to overcome the normal tendency of the receiver's bandwidth to change as the receiver is tuned from one end of the broadcast band to the other. This assures that the receiver will be equally selective for all regions of the broadcast band. If an r-f amplifier stage were designed only for getting maximum transfer of signal from one tube to the next, and complete coverage of the broadcast range, the bandwidth of the stage would almost certainly vary as shown



variable bandwidth and constant bandwidth curves

Fig. 28-13

in Fig. 28-13 at a, b and c. If we tuned from the low to the high end of the broadcast band by varying inductance, the gain of the stage would decrease and its bandwidth would increase, because we would have to use lowered inductance to resonate with the fixed capacitor at 1650 kcs. The reactance of the greatly reduced inductance would be less at 1,650 kc than it was at 530 kc, when the inductance was nine times as much.

The ohmic resistance of the coil would not change as the slug moved in or out. The reactance would change. The Q would change in proportion to the change of reactance, X_L, because Q equals $\frac{X_L}{R}$. Since reactance would be less at the high end of the band, Q would also be less. Therefore, gain would be less and bandwidth broader. The loss in gain would not be as serious a matter as the increase in bandwidth. Low r-f gain can be offset to a large extent by advancing the audio-volume control. But the increase in bandwidth, with resultant interference between stations, could not be compensated for.

If we tuned by varying capacitance instead of varying inductance, as we varied the capacitor we would be changing our L/C ratio. This affects selectivity. We might find that the bandwidth became broader as we tuned from the high end to the low end of the broadcast band.

The goal of professional designers, which they came close to, is a resonant curve such as that shown at *d*, *e*, and *f* in the figure. The bandwidth is the same for all parts of the broadcast band. You should remember to use exact replacement parts when repairing damaged resonant circuits so that this curve will remain the same.

28-6. VARIABLE CAPACITORS

Design engineers found that the problems encountered in maintaining nearly constant bandwidth throughout the broadcast band were fewer if tuning was accomplished by varying capacitance. This method of tuning became almost universal, and remained the principal method, even after the development of high-permeability cores of powdered iron made compact variable inductors practical.

The variable capacitor consists of two sets of metal plates usually of aluminum, held rigidly in the correct relationship to one another by a strong metal frame. One set of plates, called the rotors, is attached to a shaft. The other set of plates, called the stators, is held in place by insulating spacers. The arrangement is shown in Fig. 28-14. The rotor plates are connected by the metal shaft to the metal frame. The stators are insulated from the frame by their spacer supports, and from the rotors by air spaces.

As the shaft is turned, the rotors turn with it. The thin rotor plates fit into the spaces between the stators, when the shaft is turned to the closed, or fully meshed, position. The rotors never actually touch the stators, but their smooth plane surfaces are very close to the surfaces of the stators, so that considerable capacitance exists between the two sets of plates.

As the shaft is turned in the other direction, the rotors are gradually withdrawn from the spaces between the stators, so that the capacitance between the sets of plates diminishes. When the shaft has been rotated 180 degrees, the rotors are fully out of mesh.

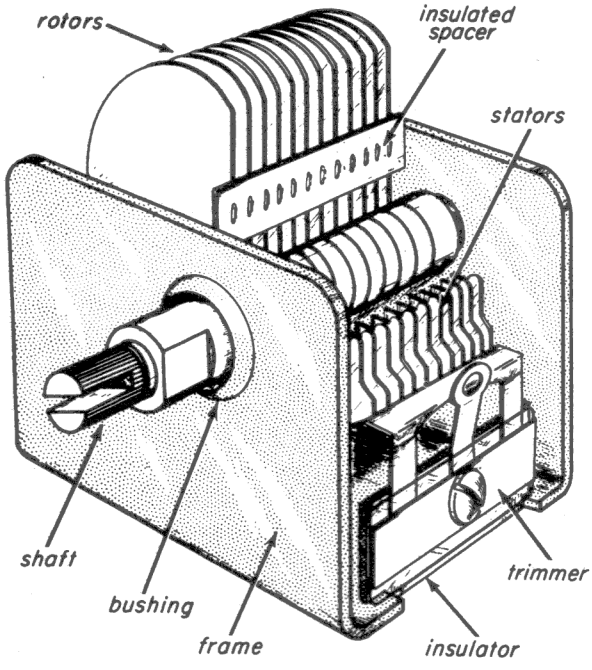


Fig. 28-14

Capacitance is at a minimum. For a capacitor intended to cover the broadcast band, this minimum capacitance is about 25 $\mu\mu$f.

An additional small capacitor, called a trimmer, is usually mounted on the insulating spacer, and is connected in parallel with the variable capacitor. It is adjusted by turning a screw. Its range is roughly 5 to 25 $\mu\mu$f. Its capacitance, added to the minimum capacitance between rotor and stator, determines the overall minimum capacitance of the combination. By adjusting the trimmer, the overall minimum may be set anywhere between 30 and 50 $\mu\mu$f.

The trimmer is very useful for causing a station to come in at its correct setting on the receiver's dial – that is, for calibrating the tuning system. Suppose, for instance, that the inductor connected across the variable capacitor has a value of 230 μh. Suppose that when the capacitor is wide open, the indicator, being correctly in step with the rotor plates, points to the extreme end of the band, 1,650 kc (see Fig. 28-15). But, suppose also that a station transmitting on 1,650 kc does not come in until we mistune the receiver. It comes in when the indicator points at the wrong frequency, 1,600 kc, as shown in the figure by the dashed line.

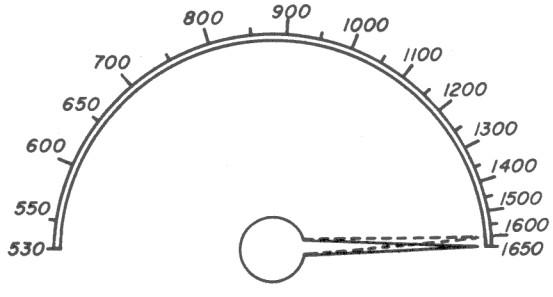


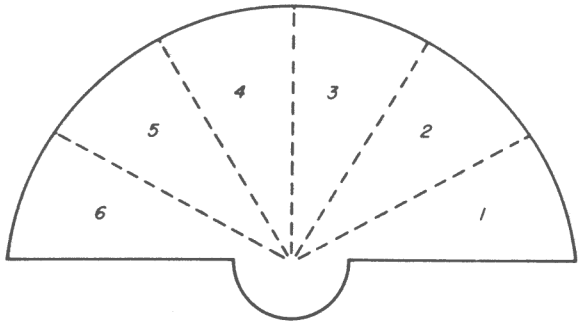
Fig. 28-15

We interpret this misalignment as follows. We had to close the capacitor slightly to make the *LC* combination resonate at 1,650 kc. That is, we had to add more capacitance. Therefore, minimum capacitance was not enough to resonate the combination when the capacitor was in the position where the indicator pointed at the correct frequency. What we should do is leave the variable capacitor in the position of correct indication, and increase the capacitance, not by closing the variable capacitor, but by closing the trimmer more. When we close the trimmer until the total minimum capacitance is about 40 $\mu\mu$f, the 230 μh inductor will resonate with it at 1,650 kc.

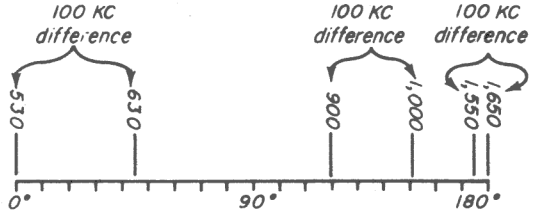
The trimmer should not be used to make adjustments for stations at the low end of the dial. It is intended strictly for the purpose of adjusting (trimming) the minimum capacitance. Adjustments for misalignment at the low end are seldom needed when the high end is correctly calibrated.

28-7. VARIABLE CAPACITOR PLATE SHAPES

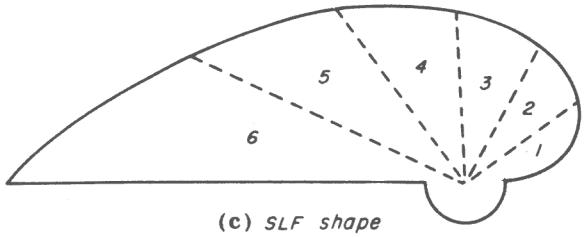
The simplest shape for the rotor plates that would allow complete meshing, and then complete unmeshing, upon rotating the shaft 180 degrees is a semi-circle, is shown in Fig. 28-16*a*. While this would be a very convenient shape mechanically, it is unsatisfactory for electrical reasons. As shown in the figure, where the plate is divided by dashed lines into thirty-degree segments, rotating the shaft thirty degrees clockwise would bring segment 1 into mesh, thus increasing the minimum capacitance by a certain amount – perhaps 60 $\mu\mu$f. Rotating it another thirty degrees would add another 60 $\mu\mu$f, and so on. Each thirty degrees of rotation would bring the same amount of additional capacitance



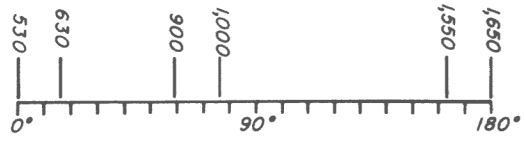
(a) *semicircular shape*



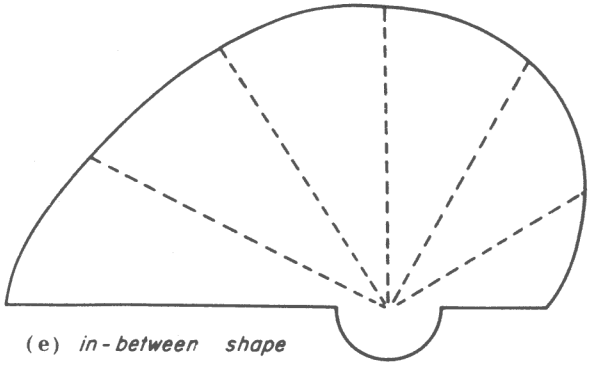
(b) *carrier frequency spacing with semicircular rotor plates*



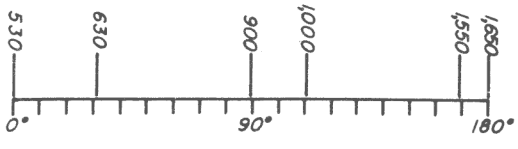
(c) *SLF shape*



(d) *carrier frequency spacing with s-L-F rotor plates*



(e) *in-between shape*



(f) *carrier frequency spacing with in-between shape*

Fig. 28-16

into the resonant circuit. This uniform increase of capacitance with rotation is undesirable because of the way a change in capacitance changes the resonant frequency. At the high end of the broadcast band, the resonant frequency is changed greatly by a small change of capacitance. At the low end of the band, about nine times as great a capacitance change is needed to produce the same amount of change in the resonant frequency.

For example, with a 230-μh inductor, a capacitance of 40.4 $\mu\mu$f is required for resonance at 1,650 kc. For resonance at 1,550 kc (100 kc lower), a capacitance of 45.9 is required. The difference, 5.5 $\mu\mu$f, is the amount of capacitance the variable capacitor must add, by rotating, to the resonant circuit in order to tune the circuit, originally at 1,650 kc. to 1,550 kc. With semi-circular plates, this would call for a rotation of less than three degrees. Such a small amount of rotation would move the dial indicator only a little bit, and, as a result, the stations would have to be marked very close together on the dial. A dial suited to such a capacitor would have stations, separated by 100 kc crowded close together at the high end (see Fig. 28-16b). With this crowding, stations separated by only 20 kc would come in so nearly at the same place that the owner of the set could not be sure which one he was listening to. Furthermore, adjusting the tuning knob with sufficient accuracy to have the capacitor right "on" the station would be difficult.

At the low end of the band, the difficulty would be just the opposite of crowding – stations only 100 kc apart would be widely spaced on the dial. To tune from 630 kc to 530 kc would require a capacitance change of almost 50 $\mu\mu$f. The capacitor would have to rotate about 25 degrees to insert the additional capacitance required. So much rotation would move the indicator much further than the less-than-three-degrees rotation at the high end of the dial moved it. It would, in fact, move the indicator nine times as far as shown in the figure.

If the plates of the capacitor could be modified in such a way that each degree of rotation would insert very little capacitance

at the high end of the frequency band and each degree of rotation would insert nine times as much capacitance at the low end of the band, with proportional amounts per degree in between, all stations separated by 100 kc would have the same physical separation on the dial.

Figure 28-16*c* shows a plate shape that would provide this desirable action. It is called the straight-line-frequency (*slf*) shape, because of the graph that describes it. If the change in frequency due to rotating the capacitor is plotted against the degrees of rotation, the resulting line is straight.

When the segments are rotated 30 degrees clockwise from the fully open position, segment 1 is brought into mesh. Note that segment 2 is larger than segment 1. Furthermore, segment 3 is larger than segment 2, and so on. Segment 6 is largest of all. Its area is nine times greater than the area of segment 1. In short, at the low end of the broadcast band, thirty degrees of rotation makes a change in capacitance nine times greater than thirty degrees of rotation at the high end.

On a dial suited to this plate shape, spacing of stations would be as shown in Fig. 28-16*d*. Obviously, the plate shape which produces this spacing is just right electrically.

But it is not just right mechanically. At the half closed position, the long end of the plate sticks far out from the rest of the variable capacitor. It takes up too much room in the receiver. Its center of gravity is so far from the center of rotation that it tends to fall out of adjustment due to its own weight, particularly when subject to vibration, as from traffic passing by.

A compromise shape, Fig. 28-16*e*, adapted by designers is roughly midway between the semicircular and the *slf* shape. It produces a spacing of stations approximately as shown in Fig. 28-16*f*. It takes up less room than the *slf* shape. Its center of gravity is closer to its center of rotation. It does not tend to shift position as much as the *slf* shape. The spacing it provides affords adequate readability.

28-8. TRIODE TRF AMPLIFIERS

Up to now, no mention has been made of using triodes as amplifiers in TRF circuits, even though triodes were extensively used as such in the early days of the TRF receiver.

Pentodes are used instead of triodes as r-f amplifiers. They result in higher gain than the triode and have far less effective capacitance between plate and grid. The screen and suppressor grids, which were added to the triode to change it to a pentode, so completely shield the plate from the control grid that the effective capacitance between the input and output electrodes is so little that it can be neglected. This overcomes one of the drawbacks of triodes which have considerable capacitance between grid and plate. This capacitance can act as a coupling capacitor, feeding signal energy back from the plate to the grid. But in order for a tuned grid circuit to be excited to resonance by feedback from the plate, the feedback signal must be positive in phase, or at least, considerably less than 180 degrees out of phase. If the plate circuit is tuned, the resonant plate load is neither inductive nor capacitive, since these two effects cancel at resonance. The plate load is resistive, and its output signal is 180 degrees out of phase with the input. However, if the plate circuit is detuned slightly to a higher frequency, it will become inductive. The output will be less than 180 degrees out of phase with the input, and there will be feedback. This feedback produces a condition called *oscillation*, which we will consider in a lesson later. This oscillation is undesirable because it produces a whistle in the loudspeaker. The type of oscillation we are discussing is called tuned-plate tuned-grid oscillation. The feedback through the tube's internal capacitance will be of a phase to produce oscillation, which will occur at a frequency slightly different from the plate circuit's natural resonant frequency.

If the triode's plate circuit is untuned, the primary of the r-f transformer is inductive for broadcast frequencies and results in the required amount of feedback for oscillation.

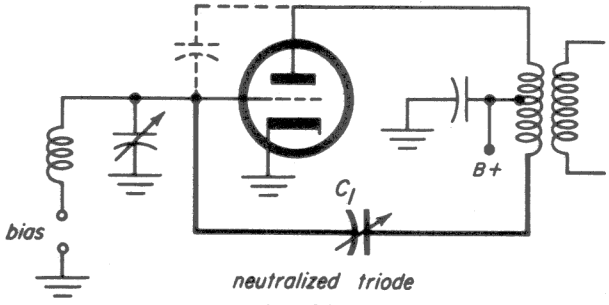


Fig. 28-17

In order to get satisfactory gain without oscillation, we have to neutralize the feedback from plate to grid – that is, we have to feed back another signal which will be opposite in phase and equal in amplitude to the feedback signal that is causing oscillation. This second feedback signal cancels, or neutralizes the undesirable feedback signal.

Figure 28-17 shows a simple circuit providing neutralization. The primary of the r-f transformer is center-tapped. $B+$ is applied at the center tap, which is bypassed so that it is held at r-f ground potential. When a signal appears at the top half of the primary, a similar signal, opposite in phase, appears at the lower half. An added adjustable capacitor, C_1 approximately equal to the internal plate-to-grid capacitance, provides a path by which the opposing signal can pass from plate to grid. C_1 is adjusted so that the amount of opposing signal just equals, and therefore cancels, the internal feedback signal. This arrangement enables the triode to operate at its fullest capability.

When pentodes were developed, they proved to be as immune to internal feedback as neutralized triodes, and they provided much higher gain. Except in special application they are used instead of triodes as r-f amplifiers.

Economy TRF Midget Receivers. These tiny sets were produced in great numbers when people first became interested in small table top receivers. They utilized an indoor antenna about twenty feet long, small-sized but high-gain r-f transformers, one stage of r-f amplification, and either a grid-leak or a plate detector (sometimes a diode detector) was used.

Volume was controlled by varying the r-f gain of the receiver. A variable resistor, R_1, connected as shown in Figure 28-18, had

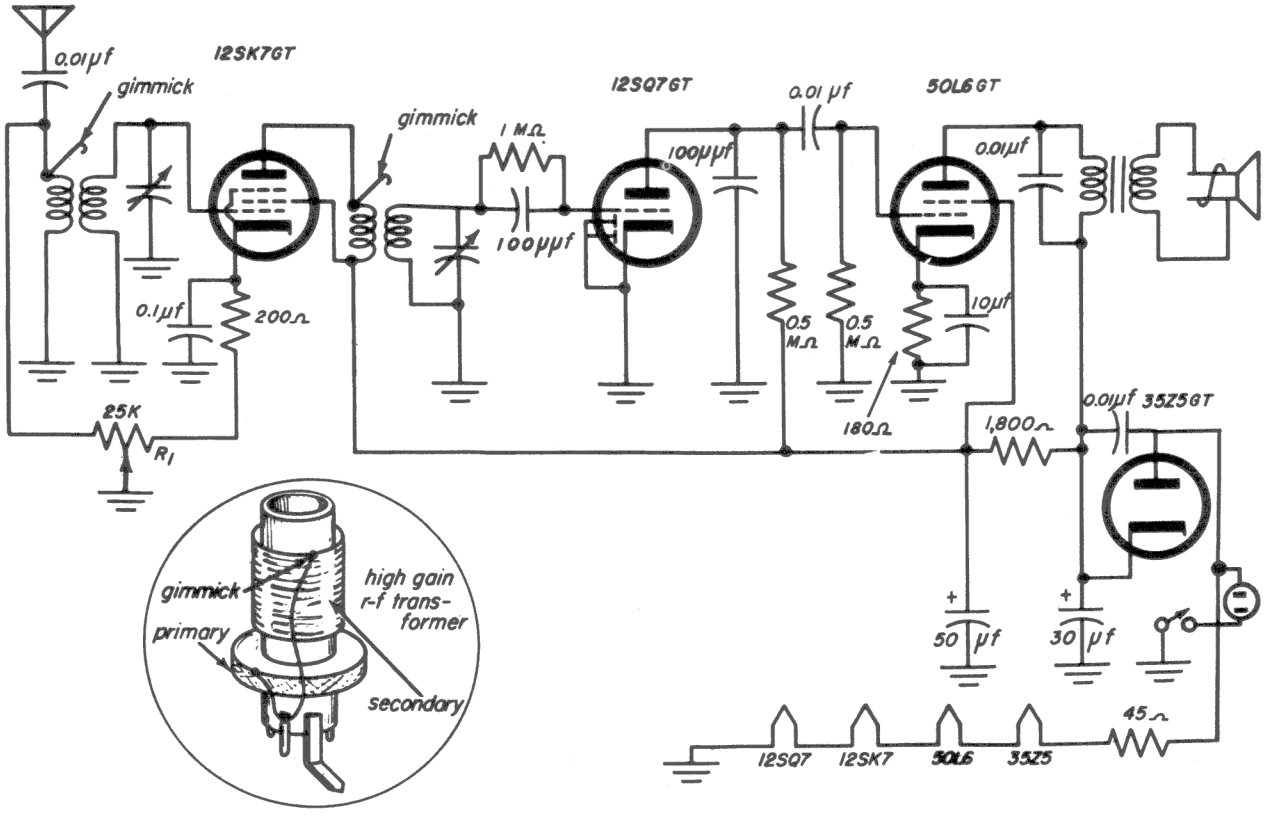


Fig. 28-18

a double action. As the grounded wiper arm was moved to the left, the signal from the antenna was shunted through the control to ground. At the same time, the resistance between cathode of the r-f amplifier tube and ground was increased, causing the tube to be almost cut off. Thus, the signal from even a very strong station could be heavily attenuated before being passed to the detector stage.

When the wiper arm was moved the other way, the antenna shunt was largely relieved, while the cathode bias was diminished by the lowered resistance between cathode and ground. The tube, working at optimum bias, provided full gain.

A wide range of signal strengths could be accommodated by appropriate adjustment of shunt and bias.

The primaries of the r-f transformers (Fig. 28-18) used were high impedance windings having many turns. They were self-resonant at a frequency just below the low end of the broadcast band. This feature boosted the gain near the low end. The "hot" (antenna or plate) end of the winding was capacity coupled to the grid end of the secondary, by a "gimmick", a turn of insulated wire, of which one end was connected to the primary. The single turn, wound around the secondary, acted as a small capacitor that transferred signal from plate to grid. At the higher broadcast frequencies, it had less reactance than at the lower frequencies, and therefore boosted the gain near the high end of the broadcast band. By this ingenious design, the gain held reasonably uniform over the whole broadcast band.

The selectivity of the receiver was poor. Its fidelity was poor. But it was small and cheap and was very popular for many years. Hundreds of thousands like it are still in use.

28-9. GANGED VARIABLE CAPACITORS

Normally, trf receivers have two or more stages of r-f amplification, tuned to the same frequency. When the receiver is tuned from one station to another, each r-f stage must be re-tuned to the new carrier.

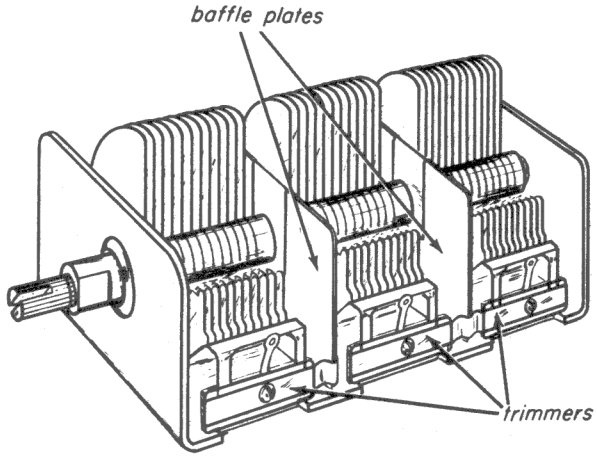


Fig. 28-19

In very early TRF receivers, a separate variable capacitor for each stage had to be separately tuned to the desired carrier frequency. The set couldn't be tuned rapidly from one end of the broadcast band to the other by rotating just one dial as we do today. In a four-stage receiver, the user had to reset four such capacitors each time he changed stations. Each capacitor had a dial, numbered from 0 to 100. If a station previously logged (that is, listed) was known to come in at 64 on the dials, he simply turned all dials to 64. (A chart for logging new stations usually hung on the wall near the receiver.)

This cumbersome method of tuning was eliminated when the multiple, or ganged, variable capacitor was invented. This capacitor featured a long shaft and a long frame. A ganged variable capacitor for a four-stage receiver had four sets of rotors on the shaft. Four sets of stators meshed with the rotors. Each set of rotors, with its corresponding set of stators, was called a *section*. Between each section and the one next to it was a thin metal wall or baffle plate, attached to the frame. This baffle plate shielded stator sections from each other, so that their electric fields were isolated, and could not interact. The rotors did not need to be shielded from each other, because they were connected together already by the common shaft, which was grounded for r.f.

A four-section variable capacitor was called a four-gang variable capacitor. A three-section version was called a three-gang variable capacitor, and so on. Fig. 28-19 shows a three-gang version. Note that all

the rotor plates are accurately in line on the shaft and all the stators accurately aligned in the frame, so that when one section is fully meshed, the others are fully meshed; when one is exactly half open the others are exactly half open; and so on. This accurate alignment is important – it assures that each degree of shaft rotation will produce the same capacitance change in each section, if all sections are designed to be identical.

By making all the r-f inductors equal, the set designer would produce a TRF receiver whose r-f stages would at all times have exactly similar amounts of inductance and capacitance in their resonant circuits. They would thus be tuned alike at all times. If one stage were tuned to a particular frequency, the others would automatically be tuned to that same frequency. Thus one shaft, with one knob, enabled the set owner to tune from one end of the broadcast band to the other, swiftly and easily. Tuning was no longer a chore.

In the next lesson, on superheterodyne receivers, you will learn about ganged capacitors that have dissimilar sections in order that they can vary two *different* frequencies simultaneously.